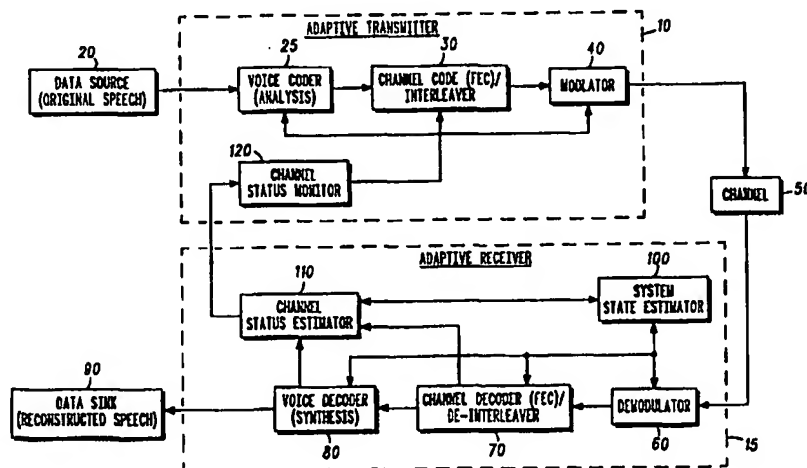




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(21) International Application Number: PCT/US98/00276 (22) International Filing Date: 13 January 1998 (13.01.98) (30) Priority Data: 08/806,783 26 February 1997 (26.02.97) US (71) Applicant (for all designated States except US): MOTOROLA INC. [US/US]; 1303 East Algonquin Road, Schaumburg, IL 60196 (US). (72) Inventors; and (75) Inventors/Applicants (for US only): KLEIDER, John, Eric [US/US]; 8501 E. Turney Avenue, Scottsdale, AZ 85251 (US). WOOD, Clifford, Allan [US/US]; 7227 S. Bonarden, Tempe, AZ 85283 (US). CAMPBELL, William, Michael [US/US]; 3953 E. Agave, Phoenix, AZ 85044 (US). (74) Agents: INGRASSIA, Vincent, B. et al.; Motorola Inc., Intellectual Property Dept., P.O. Box 10219 M, Scottsdale, AZ 85271-0219 (US).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>

(54) Title: METHOD AND APPARATUS FOR ADAPTIVE RATE COMMUNICATION SYSTEM

**(57) Abstract**

A system is disclosed for an adaptive rate voice system to provide improvements in coded operation over changing communication channel (50) conditions. This adaptive rate system efficiently determines optimal voice/channel coding rates, coding strategies and modulation/demodulation for optimum voice quality and intelligibility. A system state estimator (100), channel status estimator (110) and channel status monitor (120) provide feedback in the system to optimize the communication channel. The system maintains a continuous link despite changing channel conditions and minimizes delays through the system. Even though simple in design, it provides relatively low complexity and powerful channel coding operation. Operating conditions are thus extended for CDMA and portable communication systems. Voice intelligibility is preserved in extremely noisy or even hostile channel conditions.

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5 **METHOD AND APPARATUS FOR ADAPTIVE RATE
COMMUNICATION SYSTEM**

Background of the Invention

10 The present invention pertains to communication systems
and more particularly to adaptive rate voice communication
systems.

 Present day digital voice communication systems are
subject to degraded speech quality for changing channel
15 conditions because of large variations in digital performance
parameters such as bit error rate or received bit energy to noise
density ratio. Such systems are only usable over a slight range of
these varying channel conditions.

 In a fixed aggregate rate system the source and channel
20 coding rates are allowed to vary, but the whole sum of the voice
coding bit rate plus the channel coding bit rate is constant. Thus,
if the aggregate rate is fixed, the sum of the rates of the source
and channel coding is equal to the aggregate channel rate. The
prior art discloses the use of a variable rate speech and a
25 variable channel coding rate, but at a fixed aggregate channel
rate, the sum of the speech (source) bit rate and the channel
coding rate always being fixed. In addition, such prior art
systems also use a fixed modulation method.

 Channel conditions include such parameters as: speech
30 quality, intelligibility, the signal-to-noise ratio (S/N), symbol
error rate (SER) and bit error rate (BER) of the transmitted and
received signal. In typical wireless communication systems,
degradation of the communication channel conditions may inhibit
quality communication or may prevent communication at all.

35 Link margins of such communication channels experience
long and short duration deep fading that distorts or inhibits
communication. Such prior art voice systems are only usable over
a slight range of these varying channel conditions. Similar
conditions can occur for image transmission, digital data and
40 other communication systems in addition to voice coding
systems.

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5 Accordingly, it would be advantageous to have an adaptive
rate communication system that maintains a continuous link
despite changing channel conditions and provides a relatively low
complexity and powerful channel coding operation while being
simpler in design and minimizing delays through the
10 communication system.

Brief Description of the Drawing

FIG. 1 is a block diagram depicting an adaptive rate
15 communication system such as a voice coder system in
accordance with the present invention.

FIG. 2 is a portion of a receiver flowchart depicting the
adaptive technique for an adaptive rate communication system in
accordance with the present invention.

20 FIG. 3 is the other portion of the receiver flowchart
depicting the adaptive technique for an adaptive rate
communication system in accordance with the present invention.

FIG. 4 is a transmitter flowchart depicting the adaptive
technique for an adaptive rate communication system such as a
25 voice coder system or vocoder in accordance with the present
invention.

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5 Description of the Preferred Embodiment

-In accordance with the present invention, a novel method and apparatus for an adaptive rate communication system for optimal voice coder speech quality and intelligibility is shown.

10 The basic system accepts an audio input from a data source such as original speech from a person. A voice coder or vocoder then converts the audio input to a digital form. Next, a channel coder processes the digitized audio to give forward error control or FEC and interleaving. This digitized audio is then modulated by
15 a modulator and transmitted over a suitable communication channel to a receiver for demodulation.

The demodulator, channel decoder/de-interleaver and voice decoder of the receiver reconstruct the digitized audio. This is provided to some data sink as the reconstructed speech. Current
20 state of the art vocoder systems use fixed aggregate rates for the transmitter. The channel coding FEC bit rate plus the vocoder rate is a fixed quantity. The novel system varies the modulation, FEC, and voice coder rate to achieve optimal channel operating conditions.

25 Variation of the modulation method is central since this achieves considerable gain in the system capability. Digital transmitted speech can withstand bit-error-rates (BER) of approximately 0.1 to 1 percent and still be of good quality. At this BER, coding gains for typical FEC systems can be less than
30 gains from switching modem rates.

Complex FEC requires more computation than modulation changes. Thus switching modulation lowers the requirements of the system. Switching is based on an objective measure of the distortion in the data.

35 The current objective measure of speech quality or speech distortion indicator is based on a function of the vocoder parameters including spectral distortion, coding probability errors, pitch distortion, decision bit errors, gain distortion and others measures that could be added by those skilled in the art.
40 This optimal vocoder system minimizes channel errors with minimal equipment additions.

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5 Referring to FIG. 1, a block diagram of a typical voice communication system architecture employing an adaptive technique is shown. An adaptive transmitter 10 provides signals to an adaptive receiver 15. The purpose of the operations implemented by the hardware in the block diagram is to extend
10 the intelligibility and speech quality of a voice communication system. Improvements are for any set of audio communication channel conditions.

A data source of original speech 20 provides an input for the system, which is compressed by a voice coder or vocoder 25
15 and a channel coder/interleaver 30. An output digital signal is modulated by a modulator 40 and transmitted through a channel 50. The data receiver 15 has a demodulator 60 that provides the signal to a channel status estimator 110 as well as to the channel decoder/de-interleaver 70. A voice decoder or
20 synthesizer 80 provides decompressing of the voice, which is then input to a data sink 90 as the reconstructed speech. The voice decoder 80 also produces a spectral distortion indicator to the channel status estimator 110.

The coded data word starts with system status bits $S(i)$
25 that are used to control the transmitter and receiver states to optimize the voice transmission. The initial bit is coded to indicate if the transmitter has changed state. If the transmitter state has been changed, the next bits provided a coded new state indicator for changing the receiver to the optimum transmitter
30 state.

If the transmitter state has not been changed, the next bits transmitted after the initial bit are speech bits. This results in increased efficiency in the channel. Based on the symbol data rate of the modem, critical operating points (OP_{crit}) are
35 computed by the system state estimator 100 and coupled to the channel 50. The state estimator operation is dynamically adjusted based on the operating parameters. The channel status monitor function 120 updates the $OP_{crit}(i)$ to $OP_{crit}(i+1)$.

These critical operating points, $Op_{crit}(i+1)$, determine the
40 optimum voice coding rate in voice coder 25, channel coding rate and channel coding strategy in channel coder/interleaver 30, and

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5 modulation/demodulation process in modulator 40,
communication channel 50, receiver demodulator 60, channel
decoder/de-interleaver 70, and voice decoder 80. The system
state estimator dynamically determines operating parameters
and continuously /dynamically adjusts operation of the receiver
10 and transmitter.

Present state of the art vocoder systems have a fixed
symbol rate, so that the optimum operating parameters can only
provide a voice quality for a mild change in the communication
channel conditions. If the channel conditions change sufficiently,
15 the previous operating parameters are no longer optimal for
providing the maximum speech quality possible given the new set
of channel conditions.

In the present invention, new critical operating points are
determined in the system state estimator 100 so the system can
20 operate optimally for current channel conditions. The system is
adaptive to varying communication channel conditions such that
the optimal speech quality and intelligibility is obtained.

Channel status is defined as the state of the channel that
requires critical operating points. Status is denoted as $OP_{crit}(i)$,
25 for optimal speech quality and intelligibility for the i^{th} channel
condition.

The channel status estimator 110 measures the quality,
signal to noise ratio (S/N), and symbol error rate (SER) or bit
error rate (BER) of the received signal. The value of the $OP_{crit}(i)$
30 parameter determines the condition (or status) of the voice
communication channel.

The critical operating points are determined according to
the communication system's BER (or SER) versus the S/N and bit
sensitivity performance. Thus, as the channel status changes, so
35 must the critical operating points $OP_{crit}(i)$.

The initial state of the system can be set at a reasonable
expected channel condition, based on the average signal quality,
S/N, and BER (or SER) measured during operational testing of the
system in the field or under expected operational conditions.

40 The initial state is set by the transmitter 10, sent through
the channel as a state indicator and decoded by the system state

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5 estimator 100 in the receiver 15. The system state estimator then outputs the critical operating points for the system at the current channel condition. The state is a result of the transmission, and is denoted as $OP_{crit}(i)$. All of the encoding and decoding processes are based on the $OP_{crit}(i)$.

10 The adaptive receiver constantly monitors the received signal quality, S/N, the speech objective quality measure, and BER (or SER) and responds by way of a feedback channel to the adaptive transmitter's channel status monitor.

If the channel statistics have been determined to have
15 changed significantly enough, the channel status monitor 120 at the transmitter then computes a new set of critical operating parameters for the system. This means that $OP_{crit}(i) \neq OP_{crit}(i+1)$, where if the channel statistics were determined not to have changed significantly, $OP_{crit}(i)$ would be very similar
20 or equal to $OP_{crit}(i+1)$. The magnitude of the change in the channel statistics will thus determine which critical parameters change and to what degree of change is required.

FIG. 2 and 3 provide the flow diagram for one
implementation of the software for an optimal voice coder
25 receiver in the present invention. FIG. 4 provides the flow diagram for one implementation of the software for an optimal voice coder transmitter in the present invention.

Referring to FIG. 2 for the receiver, the voice coder system is initially synchronized, block 12, with the channel state vector or channel state indicator equal to zero, $csir = 0$. The i th
30 received signal is input (block 62) to the receiver and then decoded in block 72 to provide the current system state indicator $S(i)$. The system state indicator $S(i)$ is evaluated by the system state estimator to determine validity, block 74. If it is valid ($Y =$
35 yes), the critical operating parameters are compared to the previous one, $OP_{crit}(i)$ is compared to $OP_{crit}(i-1)$ at block 76. Unequal parameters ($N = no$) results in the $OP_{crit}(i)$ being updated to reflect the present $S(i)$, block 86 and is used to demodulate and channel decode / de-interleave the received coded signal, block
40 94. For equal $OP_{crit}(i)$ parameters in block 76, the $OP_{crit}(i-1)$ is not changed from $OP_{crit}(i)$, in the block 84 and is used to

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5 demodulate and channel decode/ de-interleave the received signal, block 94.

-If the system state $S(i)$ in block 74 is not valid, the system determines an approximate decoded system state vector $\hat{S}(i)$, block 78. This provides an approximate new state indicator. The receiver then demodulates and channel decodes / de-interleaves the data based on $OP_{crit}(i)$ equal $Op_{crit}(i-1)$ or $\hat{S}(i)$, block 88.

The receiver then estimates the signal quality, (SIG_{qual}) , signal to noise (S/N) ratio, BER, and SER, in block 96. The voice decode or synthesis is performed with $Op_{crit}(i-1)$ or $\hat{S}(i)$, block 82 and input to the data sink, block 92, which completes the receiver decoding, block 97.

An objective measure of speech quality is then determined, block 87. This is used as the input A to FIG. 3 for continuation of the receiver flow diagram. Referring to input A on FIG. 3, the channel status vector or channel state indicator $CS(i)$ is estimated, block 112.

The $S(i)$ is evaluated in the receiver, block 98, to determine the validity of the system state, $S(i)$. If $S(i)$ is valid, it is compared to the $CS(i)$, block 102. If the two are not approximately equal, then $CS(i)$ is sent to the transmitter and the counter $csir$ is set equal 0, block 118. If the two are approximately equal, then $S(i)$ is sent to the transmitter and $csir = 0$, block 116.

If $S(i)$ in block 98 is not valid, then $\hat{S}(i)$ is compared to $CS(i)$, block 104. If approximately equal, then $CS(i)$ is sent to the transmitter and the counter $csir$ is set to zero or $csir = 0$, as in block 114. If $\hat{S}(i)$ is not approximately equal to $CS(i)$, block 104, then the $csir$ counter is incremented or set $csir = csir + 1$, which is block 106.

The counter is checked to determine if the counter has exceeded a predetermined limit or Block 108 compares if $csir > N_{crit}$. If it is not, then block 124 sends $CS(i)$ to the transmitter.

If $csir$ is greater than N_{crit} , in block 108, then a resynchronization signal is sent to the transmitter, block 122. In either case, this ends the processing in the receiver on the i th channel status symbol, block 126.

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5 FIG. 4 provides one means of implementing the transmitter for the present invention. At initial power up / synch and re-synch, the state vector S is set to the initial value, and the csit counter is set to zero, or $csit = 0$, block 14. The i th channel status symbol is input, block 16. Next the channel status
10 required is decoded from the receiver, $CS(i)$ in block 18 to determine if the transmitter needs to be changed.

 The validity of the channel status, $CS(i)$, is checked in block 24. If $CS(i)$ is valid, then block 22 computes $S(i+1)$ based on the $CS(i)$. Then the $S(i+1)$ is compared to $S(i)$, block 26. If they are
15 not equal, then the transmitter updates critical operating parameters $OPcrit(i+1)$ according to parameter $S(i+1)$, block 34.

 If the system state indicator has not changed, the critical parameters are the same, or if $S(i+1) = S(i)$ then $OPcrit(i+1)$ is equal to $OPcrit(i)$, block 32. If the channel state indicator, $CS(i)$
20 is not valid, block 24, an approximate channel status $\hat{CS}(i)$, block 28 is determined. Next an $OPcrit$ is determined from $\hat{CS}(i)$, block 36.

 Finally, voice code or vocode of the input, channel code/interleave and modulate based on the $OPcrit$, block 38 is
25 performed. This ends the transmitter function, block 42, and provides the output on FIG. 1 for transmitter 10.

 The output then is sent over the channel 50 of FIG. 1 to the receiver 15 for decoding as the i th received signal, block 62, on FIG. 2.

30 It will be noted that the invention can be applied to any digital data communication channel and is not limited to voice coding systems. Thus imagery, secure data or other digital communication could be improved by the optimal communication system of the present invention.

35 Although the preferred embodiment of the invention has been illustrated, and that form described in detail, it will be readily apparent to those skilled in the art that various modifications may be made therein without departing from the spirit of the invention or from the scope of the appended claims.

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5

CLAIMS

-What is claimed is:

1. An apparatus for an adaptive rate communication
10 system characterized by:
a transmitter (10) for transmitting signals from a
source through a channel;
a receiver (15) for receiving said signals from said
transmitter, said receiver coupled to said transmitter through
15 said channel;
said receiver including a state estimator (100) for
dynamically determining operating parameters; and
said state estimator dynamically adjusting operation
of said receiver based upon said operating parameters, said state
20 estimator coupled to said channel.
2. An apparatus for an adaptive rate communication
system as claimed in claim 1, wherein said state estimator
determines whether said operating parameters are changed to new
25 operating parameters, said state estimator operating said receiver
to process said signals in response to said new operating
parameters, and
wherein said receiver further includes a demodulator for
producing a signal-to-noise ratio in response to said new
30 operating parameters, said demodulator coupled to said channel
and to said state estimator, and
wherein said demodulator further produces a symbol error
rate (SER) in response to said new operating parameters, and
wherein said demodulator further produces a signal quality
35 measure in response to said new operating parameters.
3. An apparatus for an adaptive rate communication
system as claimed in claim 2, wherein said receiver further
includes a channel decoder for producing a bit-error-rate (BER) in
40 response to said new operating parameters, said channel decoder

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5 for decoding said signals, said channel decoder coupled to said demodulator, and

- wherein said channel decoder produces a forward error control (FEC) in response to said new operating parameters, and

10 wherein said receiver further includes a voice decoder for producing a speech distortion indicator in response to said new operating parameters, said voice decoder for decompressing said signals, said voice decoder coupled to said channel decoder, and

wherein said signals include means for indicating a change of said operating parameters to said new operating parameters.

15

4. An apparatus for an adaptive rate communication system as claimed in claim 3, wherein said receiver further includes a channel status estimator operating in response to said signal-to-noise ratio, or to said bit-error-rate, or to said speech
20 distortion indicator to determine whether said signals are properly received by said receiver, said channel status estimator coupled to said state estimator, to said demodulator, to said channel decoder and to said voice decoder, and

25 wherein when said channel status estimator determines that said signals are improperly received by said receiver, said state estimator further operating said receiver in response to estimated operating parameters, and

wherein:

30 there is further included a feedback channel; and said transmitter includes a channel status monitor for receiving said new operating parameters from said channel status estimator through said feedback channel, said channel status monitor coupled to said channel status estimator through said feedback channel.

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5 5. A method for an adaptive rate communication system characterized by the steps of:

 (42) transmitting signals from a transmitter through a channel;

 (62) receiving said signals by a receiver from said transmitter through said channel;

 (76) dynamically determining operating parameters by a state estimator of said receiver; and

 (86) dynamically adjusting operation of said state estimator in said receiver based upon said operating parameters.

15

 6. A method for an adaptive rate communication system as claimed in claim 5, wherein said transmitting step includes a step of sending a state indicator to said receiver, said state indicator including operating parameters, and

20 wherein there is further included steps of:

 determining by the receiver whether said state indicator is valid;

 when said state indicator is valid, determining whether said operating parameters are equal to current operating parameters; and

25

 when the operating parameters are not equal to the current operating parameters, updating said current operating parameters to be the operating parameters, and

 wherein there is further included steps of:

30 demodulating said signals with said current operating parameters; and

 channel decoding said signals with said current operating parameters, and

 wherein there is further included steps of:

35 when said state indicator is invalid, approximating a new state indicator;

 update said current operating parameters based on said new state indicator;

40 demodulate said signals with said current operating parameters; and

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5 channel decode said signals with said current operating parameters, and

-wherein there is further included steps of:

estimating a signal-to-noise ratio of said signals received by the receiver;

10 estimating a bit-error-rate (BER) of said signals received by the receiver; and

estimating a symbol-error-rate of said signals received by the receiver.

15 7. A method for an adaptive rate communication system as claimed in claim 6 wherein there is further included steps of:
voice decoding said signals with said current operating parameters; and
determining a speech distortion.

20

8. A method for an adaptive rate communication system as claimed in claim 7 wherein there is further included steps of:
estimating by a channel status estimator a channel state indicator in response to said signal-to-noise ratio, to said
25 bit-error-rate (BER), to said signal quality, said symbol-error-rate and to said speech distortion;

determining whether said state indicator is valid;

when said state indicator is valid, determining whether the channel state indicator is equal to state indicator;

30 when the channel state indicator is equal to state indicator, sending state indicator to the transmitter; and

when the channel state indicator is not equal to state indicator, sending the channel state indicator to the transmitter.

35 9. A method for an adaptive rate communication system as claimed in claim 8 wherein there is further included steps of:
when said state indicator is not valid, determining whether the channel state indicator is approximately equal to the new state indicator;

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5 when the channel state indicator is approximately
equal to the new state indicator, first sending the channel state
indicator to the transmitter; and

 when the channel state indicator is not approximately
equal to the new state indicator, second sending the channel state
10 indicator to the transmitter.

10. A method for an adaptive rate communication system
as claimed in claim 9 wherein, when the channel state indicator is
not approximately equal to the new state indicator, said step of
15 second sending includes steps of:

 incrementing a counter;

 determining whether the counter exceeds a
predetermined limit;

 sending a resynchronization signal to said transmitter,
20 when the counter exceeds the predetermined limit; and

 performing said step of second sending, when the
counter does not exceed the predetermined limit, and

 wherein said step of transmitting includes steps of:

 determining whether said channel state indicator
25 received from said receiver is valid; and

 determining a transmitter state indicator from said
channel state indicator received from said receiver, if said
channel state indicator is valid, and

 wherein said step of transmitting further includes steps of:
30 determining whether said state indicator is equal to
said transmitter state indicator;

 when said state indicator is not equal to said
transmitter state indicator, updating said transmitter state
indicator to be said channel state indicator; and

35 determining said new operating parameters from said
transmitter state indicator.

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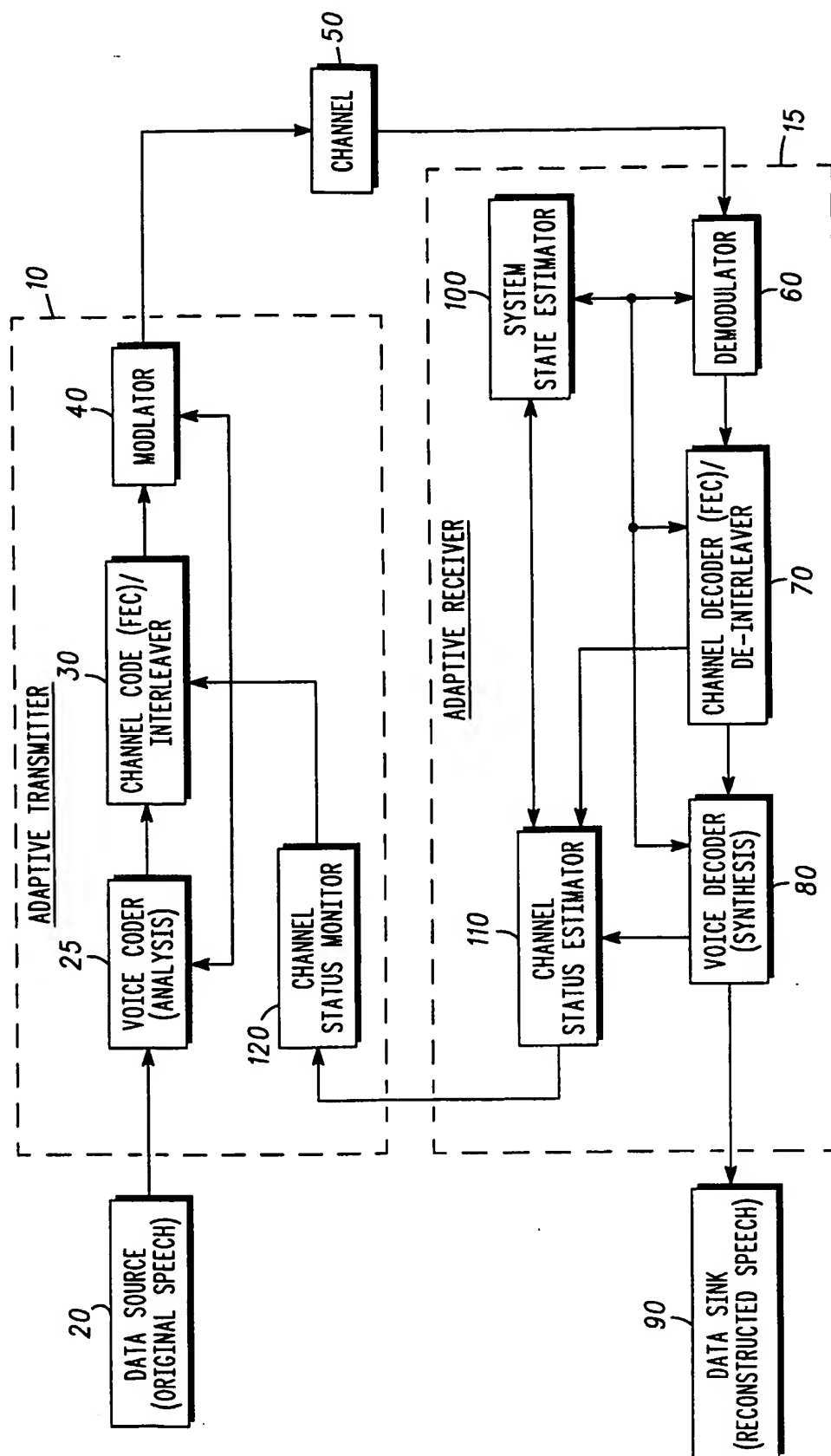
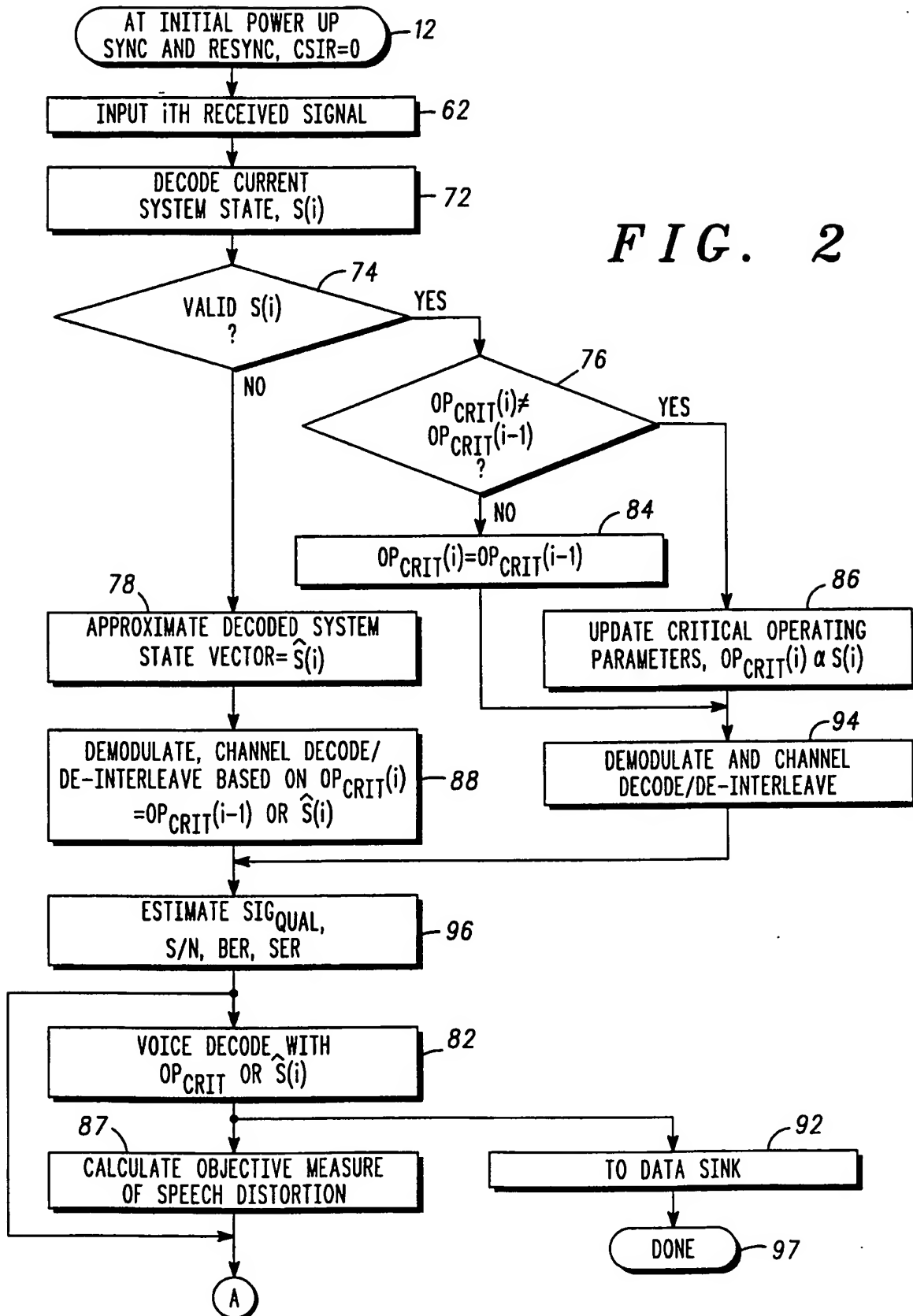


FIG. 1

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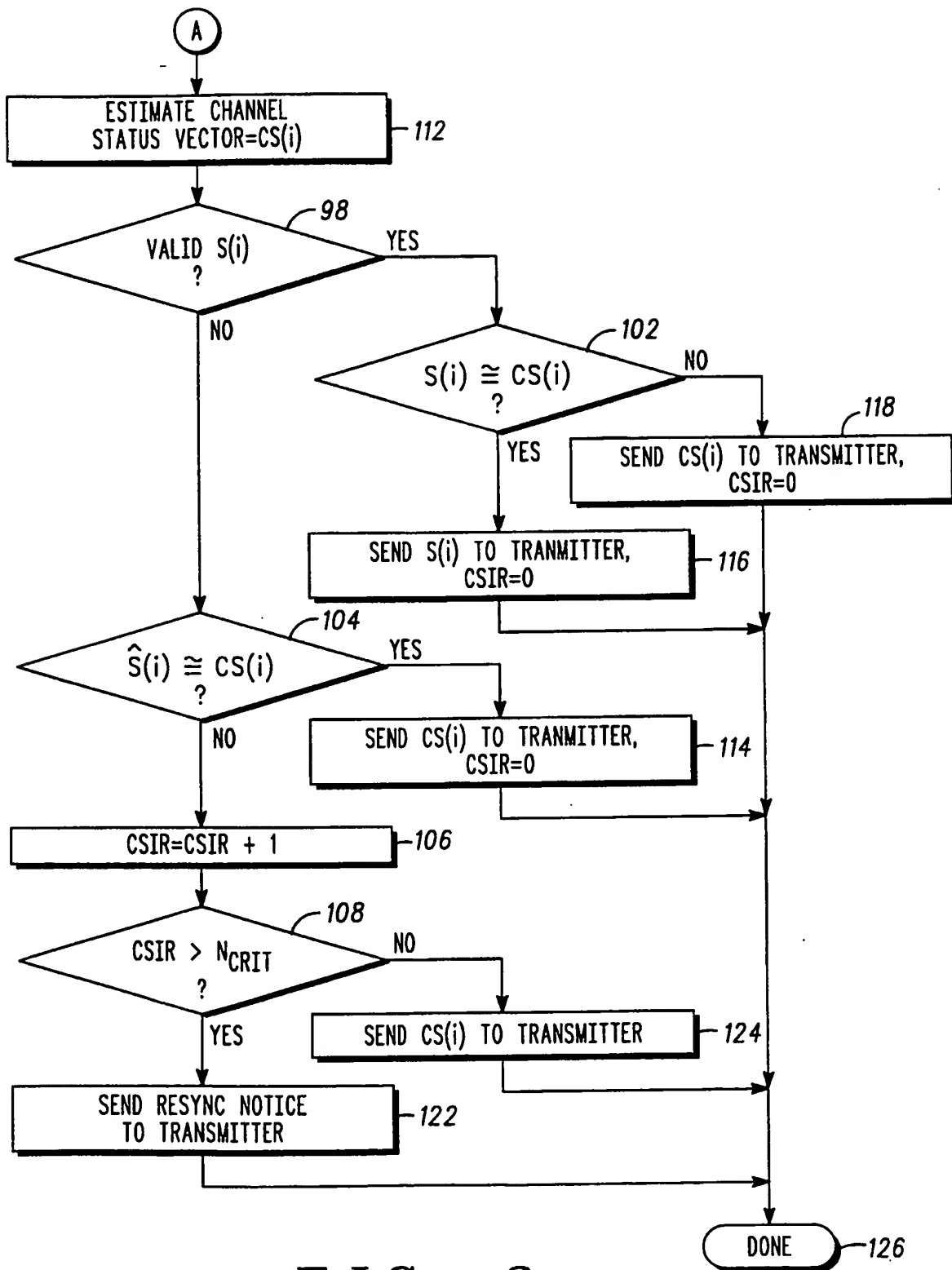
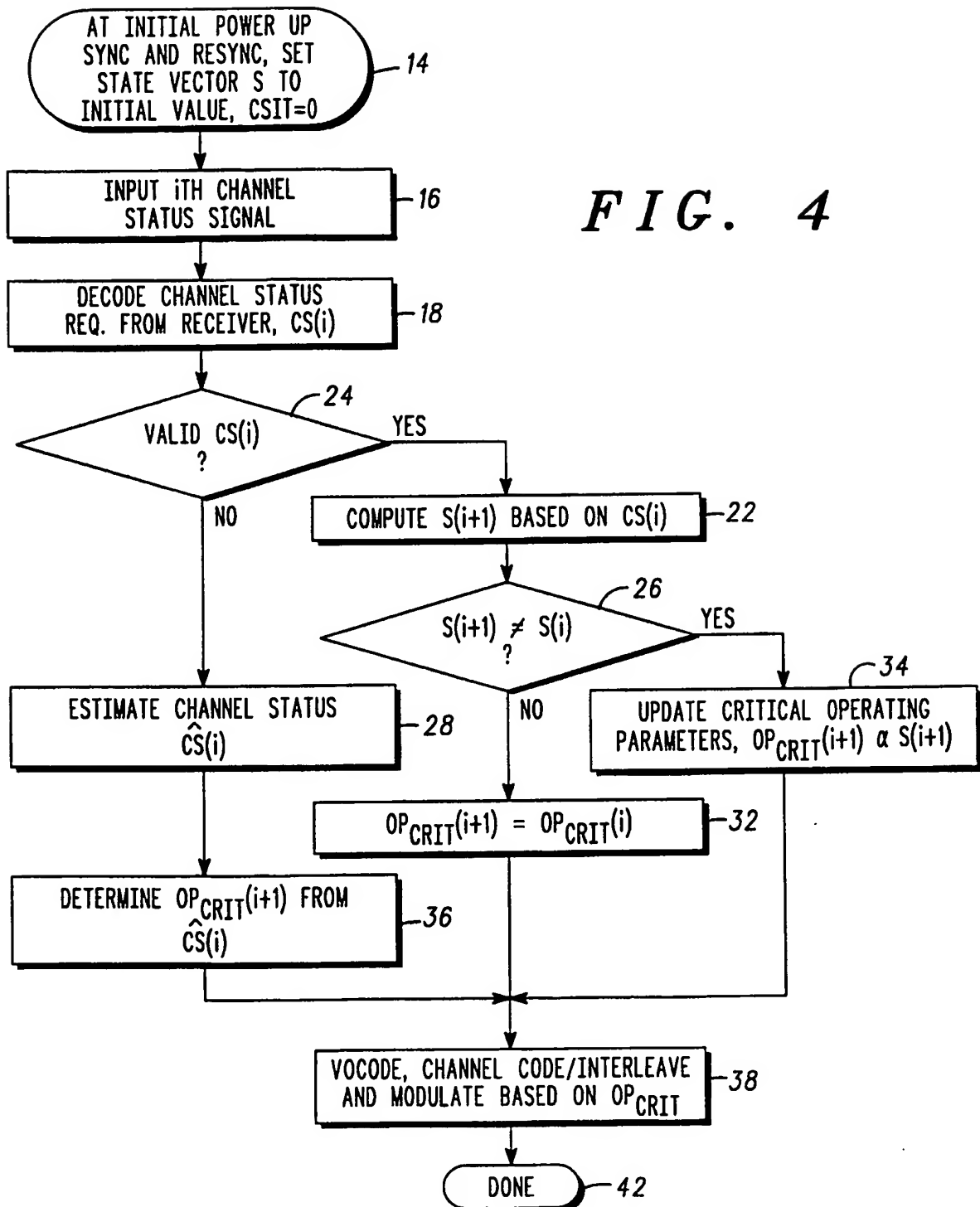


FIG. 3

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FIG. 4



INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/00276

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04L1/12

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	YUEN E ET AL.: "VARIABLE RATE SPEECH AND CHANNEL CODING FOR MOBILE COMMUNICATION" PROCEEDINGS OF THE VEHICULAR TECHNOLOGY CONFERENCE, STOCKHOLM, SE, vol. 3, 8 - 10 June 1994, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, pages 1709-1713, XP000497714	1,5
Y	see sections I, II-E	2-4,6-9
A	see figure 1 --- -/--	10

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

14 May 1998

Date of mailing of the international search report

20/05/1998

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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